AD-A120 021 AEROSPACE CORP EL SEGUNDO CA CHEMISTRY AND PHYSICS LAB F/G 10/3
NICKEL-CADMIUM CELL PERFORMANCE RECOVERY AND RECONDITIONING.(U)
SEP 82 A H ZIMMERMAN, P K EFFA F04701-81-C-0082
UNCLASSIFIED TR-0082(2945-01)-5 SD-TR-82-63 NL

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Nickel-Cadmium Cell Performance Recovery and Reconditioning

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1 September 1982

Prepared for

SPACE DIVISION
AIR FORCE SYSTEMS COMMAND
Los Angeles Air Force Station
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This report was submitted by The Aerospace Corporation, El Segundo, CA 90245, under Contract No. F04701-81-C-0082 with the Space Division, Deputy for Technology, P.O. Box 92960, Worldway Postal Center, Los Angeles, CA 90009. It was reviewed and approved for The Aerospace Corporation by W. P. Thompson, Director, Aerophysics Laboratory. Ist Lt Efren V. Fornoles, SD/YLXT, was the Project Officer for the Mission-Oriented Investigation and Experimentation (MOIE) Program.

This report has been reviewed by the Public Affairs Office (PAS) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: SD-TR-82-63	2. GOVT ACCESSION NO.: AD-A120021
3. RECIPIENT'S CATALOG NUMBER:	
4. TITLE (and Subtitle): NICKEL-CADMIUM CELL PERFORMANCE RECOVERY AND RECONDITIONING	5. TYPE OF REPORT & PERIOD COVERED:
	6. PERFORMING ORG. REPORT NUMBER: TR-0082(2945-01)-3
7. AUTHOR(s): Albert H. Zimmerman and Peter K. Effa	8. CONTRACT OR GRANT NUMBER(s): F04701-81-C-0082
9. PERFORMING ORGANIZATION NAME AND ADDRESS: The Aerospace Corporation, El Segundo, Calif. 90245	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS:
11. CONTROLLING OFFICE NAME AND ADDRESS: Space Division, Air Force Systems Command, Los Angeles, Calif. 90009	12. REPORT DATE: 1 September 1982
	13. NUMBER OF PAGES: 13
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Battery	Nickel-cadmium
Capacity	Potential
Cell	Power
Current	Reconditioning
Discharge	Voltage

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Recovery of the capacity and voltage characteristics of sealed NiCd cells by reconditioning after accelerated eclipse season simulation has been measured. Performance recovery was measured as a function of reconditioning rate for both shallow- and deep-discharge conditions, as well as for multiple reconditioning cycles. Low-rate reconditioning was most effective for recovery of capacity losses, providing up to 15% capacity improvement. Deep-discharge reconditioning was most effective for recovering both capacity and voltage losses, partic-

DD FORM 1473 (FACSIMILE)

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

19 KEY WORDS (Continued)

20. ABSTRACT (Continued)

ularly at higher rates. Multiple reconditionings increased capacity somewhat, but were most effective for recovering voltage losses. The relative merits of a range of reconditioning procedures are presented in terms of their usefulness for voltage, capacity, and power improvements.

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I. INTRODUCTION

As the trend has developed in recent years toward increasing life requirements for nickel-cadmium (NiCd) satellite batteries, periodic reconditioning procedures to maintain performance have become increasingly necessary. The reconditioning of a NiCd battery typically involves the total discharge of battery capacity, which is then followed by a full recharge. This procedure increases the utilization of battery capacity, and increases the battery voltage during discharge. The effectiveness of such reconditioning depends on the reconditioning discharge rate and the cutoff voltage to which each cell or battery is discharged during reconditioning. Recent test results[1] show that reconditioning to a very low battery voltage is very effective in maintaining long term performance, and it is generally accepted that the lower reconditioning rates are the more effective. This report presents a systematic investigation of the relative voltage and capacity improvements that can be realized by reconditioning. These studies provide these data as a function of reconditioning rate, cutoff voltage for reconditioning discharge, and number of reconditioning cycles.

Sealed NiCd satellite cells are manufactured to be capacity limited by the Ni (positive) electrode. For this reason, much of the short-term changes in cell voltage and capacity performance arise from changes in the Ni electrode.[2] It is these changes in the Ni electrode that may be recovered by reconditioning. Some experimental data suggest that reconditioning may cause improvements in the Cd crystallite size distribution in the Cd electrode;[3,4] however, as long as the cells are positive limited during both charge and discharge, such reconditioning is unlikely to significantly affect performance.

II. EXPERIMENTAL

The cell used in these experiments was a 10-Ah sealed NiCd cell manufactured by General Electric for satellite use. This cell was about 8 years old, but had not been extensively cycled. The cell construction incorporated polypropylene separators and Cd in the Ni electrode as an antipolar mass. Prior to each experiment the cell was first discharged for 16 h through a resistance of 1 Ω, charged for 16 h at the C/10 rate, then cycled 37 times to generate the kind of voltage and capacity losses that might occur during geosynchronous satellite eclipse season operation. These 37 cycles were to a 40% depth-of-discharge (DOD); each cycle consisted of discharge for 1 h at 4 A, recharge at 2.5 A for 1.28 h (80% return), and recharge at 1 A for 1.6 h (120% total charge return). The cell was then discharged to 1.1 V at 4 A so that a baseline capacity could be obtained, then was reconditioned at the desired rate to a voltage level of either 1.1 or 0.01 V. After this reconditioning the cell was recharged at C/10 for 16 h, which was followed by a 4-A capacity discharge to 1.1 V. The capacity recovery resulting from reconditioning is the increase in this capacity over the previously measured baseline capacity. To examine effects of a second reconditioning cycle, the reconditioning discharge, recharge, and capacity discharge were repeated a second time.

The sequences of charge, discharge, and reconditioning described above were automatically performed by a microprocessor-controlled battery cycler that was used to program a Powermate BPA-20E power supply. The cell voltage during cycling was continuously monitored during all experiments, and was stored in microprocessor memory at prescribed intervals during charge and discharge, as well as at the end of each charge or discharge. The resolution of the voltage data was ± 0.1 mV. Placing the cell in a temperature-controlled bath that used ethylene glycol as the heat transfer fluid maintained cell temperature at 20.00 ± 0.05°C for all experiments.

III. RESULTS AND DISCUSSION

Reconditioning rates of 0.1, 0.5, 2.5, and 4.0 A were used in conjunction with reconditioning cutoff voltages of 0.01 and 1.1 V. The results of these experiments are presented in Table 1. The average voltage during each discharge was computed as the time integral of the cell voltage during discharge divided by the discharge duration. This integration was done numerically using a 200-s sampling time. Experiments are also presented for several second reconditionings, so that the relative merits of multiple reconditioning may be examined. Figure 1 indicates how the capacity improvement resulting from reconditioning depended on reconditioning rate for the two cutoff voltages of 1.1 and 0.01 V. Figure 2 similarly plots the improvement in average discharge voltage that results from reconditioning. The data in Table 1 yield the increase in power afforded by reconditioning at rates from C/100 to C/2.5. The power increase ranges from 17.6% with two C/100 reconditionings to 0.01 V, to only 3.2% when one C/2.5 reconditioning discharge to 1.1 V is employed.

The data in Figs. 1 and 2 provide a useful overview of the relative merits of various reconditioning procedures. The most obvious point is that the very low reconditioning rates are more effective than the higher rates for recovery of both voltage and capacity. For capacity recovery, the best procedure is to employ a low-rate reconditioning discharge to a cutoff of 0.01 V. For voltage recovery, low-rate, deep-discharge reconditioning is also most effective; however, several reconditioning cycles to a cutoff of 1.1 V at rates up to C/10 can provide effective voltage recovery. The relative merits of a number of different possible reconditioning schemes are summarized in Table 2 for the recovery of both voltage and capacity. In many systems the power delivered by a battery is of primary importance; therefore, the overall merit of reconditioning procedures is best expressed by a relative power-recovery factor, which is presented in the last column of Table 2.

The results described here are for NiCd cell reconditioning after 37 cycles at 40% DOD. The maintenance of performance over many such cycling

Table 1. Capacities and Average Voltages Before and After Reconditioning for a 10-Ah NiCd Cell

Reconditioning Rate	Reconditioning Voltage Cutoff	Capacity (Ah) C/2.5		Average Voltage	
		Before	After	Before	After
C/100	0.01	11.04	12.40	1.2141	1.2382
C/20	0.01	10.95	12.05	1.2141	1.2377
C/4	0.01	11.02	11.97	1.2141	1.2322
C/2.5	0.01	11.00	11.87	1.2141	1.2314
C/100	0.01	10.86	12.38	1.2106	1.2360
C/100*	0.01	10.86	12.40	1.2106	1.2459
C/100	1.1	11.23	12.22	1.2116	1.2323
C/100*	1.1	11.23	12.48	1.2116	1.2392
C/4	1.1	11.10	11.55	1.2216	1.2308
C/4*	1.1	11.10	11.58	1.2216	1.2339
C/2.5	1.1	11.04	11.34	1.2183	1.2255
C/2.5*	1.1	11.04	11.55	1.2183	1.2302

*These reconditionings were the second ones done repetitively at this rate.

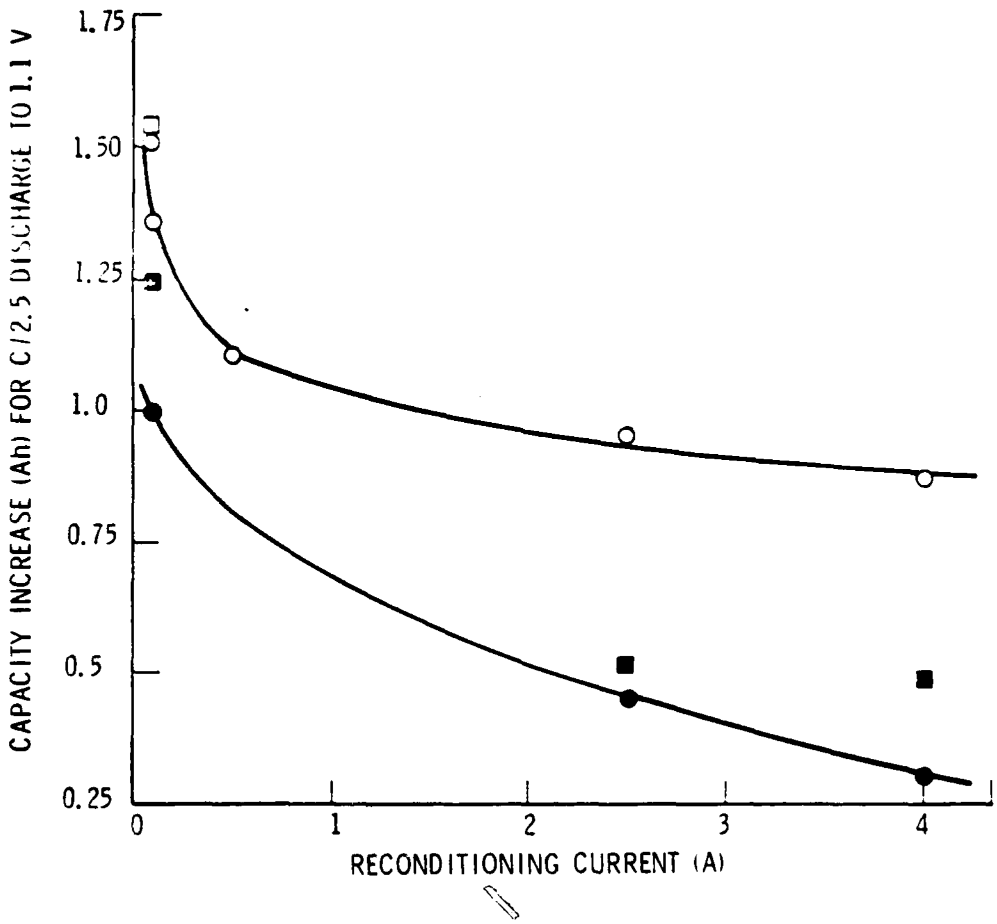

Fig. 1. Capacity Enhancement of NiCd Cell from Reconditioning. Open circles are for a single reconditioning discharge to 0.01 V, open squares are for two discharges to 0.01 V, closed circles are for a single reconditioning discharge to 1.1 V, and the closed squares are for two discharges to 1.1 V.

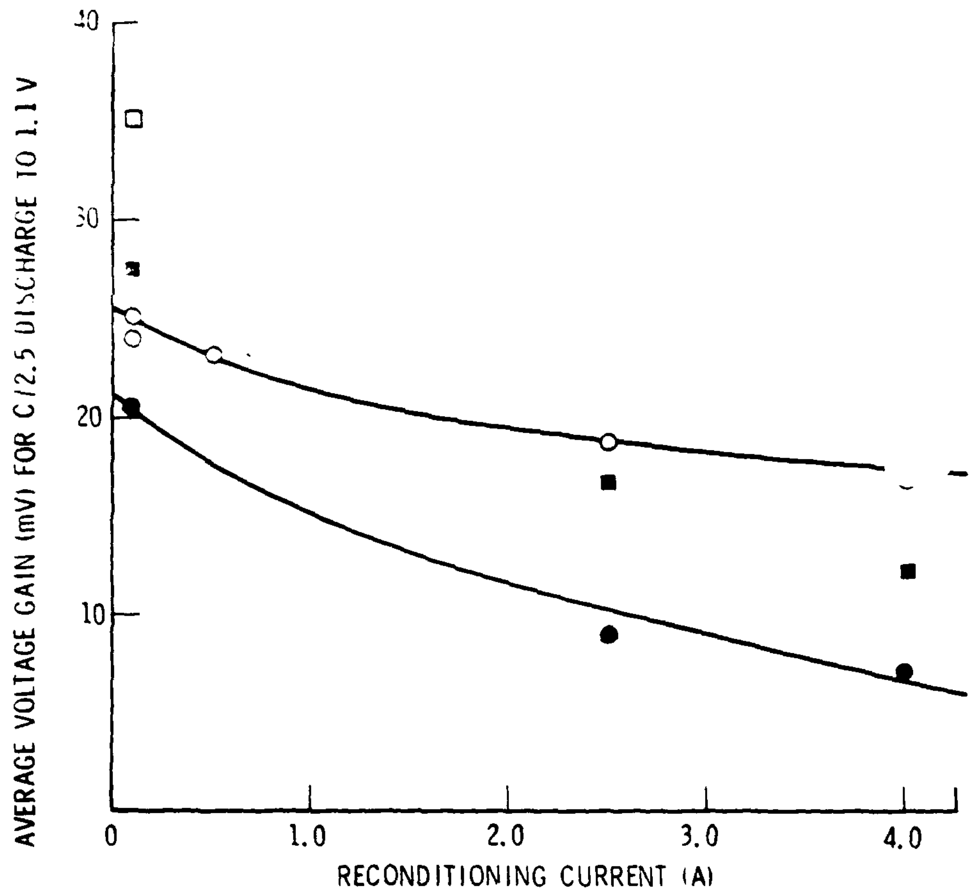

Fig. 2. Average Enhancement of NiCd Cell Voltage during a Capacity Discharge from Reconditioning. Open circles are for a single reconditioning discharge to 0.01 V, open squares are for two discharges to 0.01 V, closed circles are for a single reconditioning discharge to 1.1 V, and the closed squares are for two discharges to 1.1 V.

Table 2. Relative Merit of Common Reconditioning Procedures for Short-Term Maintenance of NiCd Cell Capacity and Voltage

	Voltage	Capacity	Overall
A. Single low-rate (C/100) cycle, to 0.01 V	0.72	0.99	0.94
B. Two low-rate cycles, to 0.01 V	1.00	1.00	1.00
C. Single low-rate cycle, to 1.1 V	0.59	0.64	0.63
D. Two low-rate cycles, to 1.1 V	**0.78**	**0.81**	**0.81**
E. Single C/10 cycle to 1.1 V	0.43	0.43	0.43
F. Two C/10 cycles to 1.1 V	0.61	0.52	0.54
G. Single capacity discharge to 1.1 V, C/2.5	0.20	0.19	0.19
H. Single C/10 cycle to 0.01 V	0.71	0.61	0.67

periods over many years can only be inferred from the data. The experiments summarized in Figs. 1 and 2 cover about 1 year and 20 reconditioning cycles. No permanent voltage or capacity losses were accumulated over this period; therefore, regular deep-discharge, low-rate reconditioning, sometimes involving multiple reconditioning, is very effective in maintaining cell performance. The cumulative effects of shallow-discharge, high-rate, or infrequent reconditioning for NiCd cells are best determined by an appropriately designed real-time life test. For a NiCd battery containing a number of cells, the relative effectiveness of deep-discharge reconditioning is expected to improve substantially over shallow-discharge reconditioning, since the cells within the battery are not generally matched in terms of capacity. Reconditioning to near zero volts for the battery is the only way to ensure that all cells are discharged to low voltages. However, this must be done at a very low rate to prevent damage to the lower-capacity cells resulting from overdischarge or reversal.[5,6]

These results are for a single cell that was relatively old. The quantitative effects of reconditioning may vary for cells of different designs, ages, or use conditions. In addition, the statistical distribution of performance improvement by reconditioning a given cell type is not known at present. However, the general trends found here for performance improvement resulting from reconditioning are expected to be generally applicable.

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